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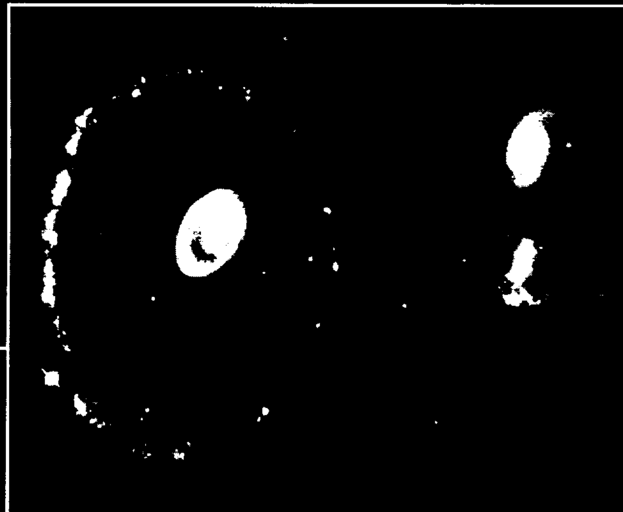
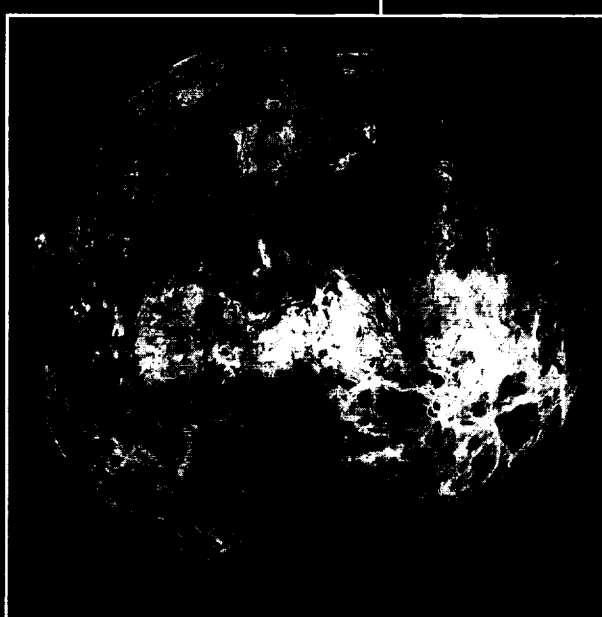


Space Science for the 21st Century:

The Space Science Enterprise Strategic Plan



National Aeronautics and Space Administration
August 1995

Cover images

1—Virtual Reality
Using telerobotic technology, the public was able to interact with a robotic submarine explorer in distant Antarctica from the comfort of the National Air and Space Museum. (NASA)

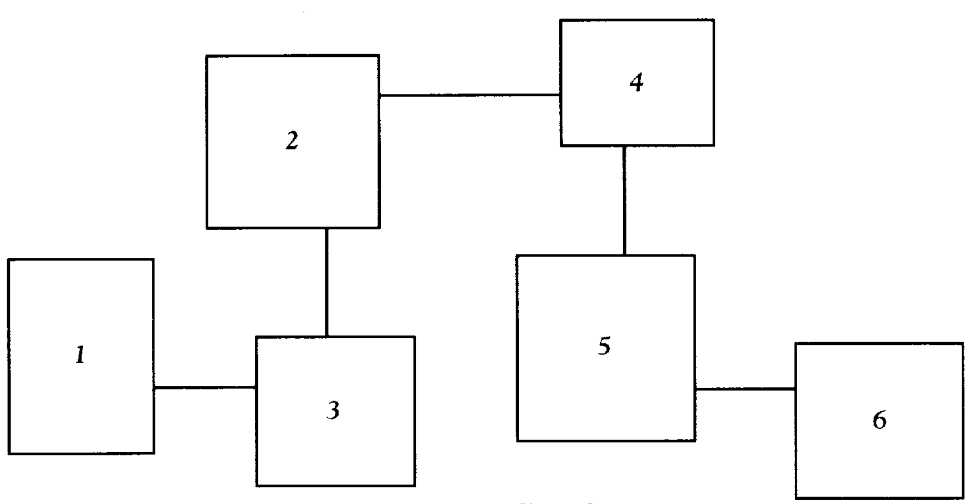
2—Hubble Space Telescope Image of Mars
This NASA Hubble Space Telescope view of the planet Mars is the clearest picture ever taken from Earth, surpassed only by closeup images sent back by visiting space probes. The picture was taken on February 25, 1995, when Mars was at a distance of approximately 65 million miles (103 million kilometers) from Earth. To the surprise of researchers, Hubble images showed that the Martian climate has changed since the Viking spacecraft visited Mars in the mid-1970s, the last time scientists got an extended look at weather on the Red Planet. The planet now appears to be cooler, clearer, and drier than it was during the Viking era.

3—Sprites
This first true color image of a sprite was obtained over a thunderstorm in the Midwest. Sprites are very short-duration optical flashes and seem to be associated with intense cloud-to-ground lightning strokes. They are predominantly red, but with occasional blue tendrils extending downward. The top of the sprite extends into the ionosphere, reaching altitudes of 90 kilometers (56 miles). The blue root-like tendrils beneath the sprite are as low as 60 kilometers (38 miles). Sprites are similar to aurora in their brightness.

4—Cartwheel Galaxy
A rare and spectacular head-on collision between two galaxies appears in this Hubble Space Telescope true color image of the Cartwheel galaxy, located 500 million lightyears away in the constellation Sculptor. The new details of star birth provide an opportunity to study how extremely massive stars are born in large fragmented gas clouds. (NASA)

5—Magellan Map of Venus
This hemispheric view of Venus obtained from the 1990–1994 Magellan mission, is centered at 90 degrees east longitude. The Magellan spacecraft imaged more than 98 percent of Venus at a resolution of about 100 meters.

6—Education
Seventh grade students tour NASA's Earth Resources aircraft hanger as part of an all-day astrophysics/airborne astronomy event at Ames Research Center. (Edna DeVore, SETI Institute, Mountain View, California)



Back Cover **Front Cover**

Space Science for the 21st Century:

The Space Science Enterprise Strategic Plan

National Aeronautics and
Space Administration
September 1995

National Aeronautics and
Space Administration

Office of Space Science

Dear Colleague:

I am pleased to release the Space Science Enterprise Strategic Plan. The Space Science Enterprise is one of five strategic enterprises through which NASA accomplishes its mission, serves its customers, and provides benefits to the Nation. The other four are Mission to Planet Earth, Aeronautics, Human Exploration and Development of Space, and Space Technology.

This Plan is an amalgamation and updating of the Office of Space Science (OSS) Strategic Plan published last year in three volumes: a Science Plan, an Integrated Technology Strategy, and an Education Plan. The purpose of the Space Science Enterprise Strategic Plan is to describe what space science is, why and how we do it, and its relevance to America; to examine the changing political and fiscal environment and articulate how we must change our behavior to succeed in the changing environment; and to present specific near- and long-term goals and strategies for achieving them.

Space Science lies at the heart of NASA's mandate to explore. Through Space Science we look outward to the solar system and the universe beyond, revealing the unknown and formulating new mysteries to unravel. At the same time that it produces discoveries and knowledge, Space Science brings technological advances in automation, robotics, instrumentation, information technology, and communications. We also strive to realize our potential contributions to education and to the improvement of the scientific and technological literacy of all Americans.

We are committed to continuing to work with the science community and our implementing organizations and institutions to develop more creative ways of doing business. The OSS Strategic Plan on which this Enterprise Plan is based was developed in partnership with the Space Science Advisory Committee. The broadest possible involvement—including decision-makers, the public, and industry—will be vital as we continue to formulate and carry out the Space Science Enterprise.

Sincerely,

Wesley T. Huntress, Jr.
Associate Administrator for Space Science

TABLE OF CONTENTS

Page

1 **FOUNDATION OF THE SPACE SCIENCE ENTERPRISE**

1 Vision and Relevance to America
2 Mission and Goals
2 Science
4 Education and Public Outreach
5 Technology
6 Key Assumptions and Considerations
6 Principles

7 **PROGRAM FORMULATION**

7 The National Academy of Sciences and Space Science Enterprise Program Planning
7 Structural Elements

8 **ENVIRONMENTAL ASSESSMENT AND RESPONSE**

8 Changing Environment
9 Strategic Actions: The Creation of a New Cost-Performance Curve

12 **STRATEGY**

12 Science
12 The Galaxy and the Universe
14 Sun-Earth-Heliosphere Connection
17 Planetary System Origin and Evolution
21 Origin and Distribution of Life in the Universe
22 Education and Public Outreach
24 Technology
25 Strategic Relationships
25 With Other NASA Enterprises
26 With NASA Strategic Functions
26 With Other Government Agencies
27 With International Partners

28 **CONCLUSION AND SUMMARY**

29 **APPENDIX: ACRONYMS**

Foundation of the Space Science Enterprise

Vision and Relevance to America

"The Space Science Enterprise explores and seeks to understand the Sun, the Solar System, the Galaxy, and the Universe, for the benefit of humanity."

We humans have a profound and distinguishing imperative to understand our origin, our existence, and our fate. For millennia, we have gazed at the sky, observed the motions of the Sun, Moon, planets, and stars, and wondered about the universe and how we are connected to it.

The Space Science Enterprise serves this human quest for knowledge. As we do so, we seek to inspire our Nation and the world, to open young minds to broader perspectives on the future, and to bring home to every person on the Earth the experience of exploring space.

The *American public* is our principal investor as well as our ultimate customer and beneficiary. Three more direct customers, the *scientific community*, the *educational community*, and *industry*, serve to bring the benefits of Space Science to the American public. These benefits are manifested in several ways, including greater understanding of the universe, inspiration at its wonders, improved education, and advancements in technology.

Understanding and Inspiration: Space Science helps us understand our current horizon and what may lie beyond. It also inspires us to look beyond the problems of today to a universe of mystery and wonder, helping us to envision a better future. The science community converts the data from space science missions into the knowledge and understanding that inspire and benefit the public.

Education: Space Science engages young people's minds and imaginations, stimulating their interest in science and technology. This in turn leads to improved performance in science and mathematics and a more science- and technology-literate society. Providing these educational benefits is an integral part of the Space Science Enterprise. The educational community brings the knowledge and understanding developed by Space Science to our Nation's youth.

Technology: The technology development required to carry out Space Science missions yields new and often unpredictable benefits to American homes and industry. As Space Science moves toward smaller, less expensive missions, the development of micromechanical and electronic devices and technologies provides many possible avenues for commercial applications. American industry, as a partner with the Space Science Enterprise, brings the benefits of technology development to the American marketplace.

Space Science benefits Americans and all people on the Earth in other ways as well. For example, the study of other planets helps us understand how the forces that have shaped the Earth behave in other planetary settings. Volcanoes, the greenhouse effect, an ozone "hole," dust storms, erosion, impacts, and other terrestrial phenomena all occur on other planets. Studying the wide range of effects these processes have on other bodies helps us understand how the Earth has evolved as a habitat for life.

Another example is the prediction of "space weather." It may soon be possible to characterize and anticipate those violent solar storms that can profoundly affect space and Earth-based communication and electrical power distribution networks. Sun and solar wind monitors now under development, combined with advanced theoretical and empirical models of the coupling of the Sun to the Earth, are leading toward predictive capability and an understanding of space weather's dependence on solar variability.

A third example is a better understanding of the threat to human civilization posed by asteroids and other objects that could collide with the Earth. The recent impact of multiple fragments of Comet Shoemaker-Levy 9 with Jupiter has brought this hazard to the attention of millions.

A fourth example is the potential for discovering planets around other worlds, possibly even planets like the Earth that show signs of life. Such a discovery would revolutionize our view of life and our own origins. These and other benefits are an important aspect of the value of Space Science to our Nation and the world.

Space Science is thus an investment in the future—a downpayment on the future of our children. As we approach the 21st century, many of the central areas of knowledge and industry—communications, information technologies, and materials and life sciences—are intimately associated with space. Discoveries about our solar system and the universe are likely to continue providing an essential context for understanding both our terrestrial environment and our place in the cosmos. In addition, America's role as a 21st century leader will in part be reflected by the vitality of its space enterprises. History has shown that nations that explore tend to be vigorous and strong. Nations that turn inward become less prosperous and less powerful. Continued American leadership at the space frontier will be vital in the new millennium, and Space Science can pave the way.

The hundreds of galaxies seen in a single image from the Hubble Space Telescope exemplify the data that astronomers can obtain to determine the structure and evolution of the universe.

Mission and Goals

Our mission and goals are threefold—in science, education, and technology.

Science

Our science mission is to seek answers to fundamental questions about:

The Galaxy and the Universe: What is the universe? How did it come into being? How does it work? What is its ultimate fate?

The Sun-Earth-Heliosphere Connection: What causes solar variability? How does the Sun and its variability affect the Earth and other planets? How does the Sun interact with the interstellar medium?

Origin and Evolution of Planetary Systems: What was the origin of the Sun, the Earth, and the planets, and how did they evolve? Are there worlds around other stars? What are the ultimate fates of planetary systems? What threat is posed by the potential for collisions with Earth-approaching objects?

Origin and Distribution of Life in the Universe: How did life on the Earth arise? Did life arise elsewhere in the universe?

We address these questions by establishing a continuum of exploration and science. We create a virtual presence in the solar system through single spacecraft scouting and exploring new territories and through constellations of spacecraft investigating the solar system in all its complexity. We simultaneously probe the universe to the beginning of time, looking ever deeper with increasingly capable telescopes, scanning the entire electromagnetic spectrum from gamma-rays to radio wavelengths. And we send probes into interstellar space, beginning a virtual presence even beyond our solar system.

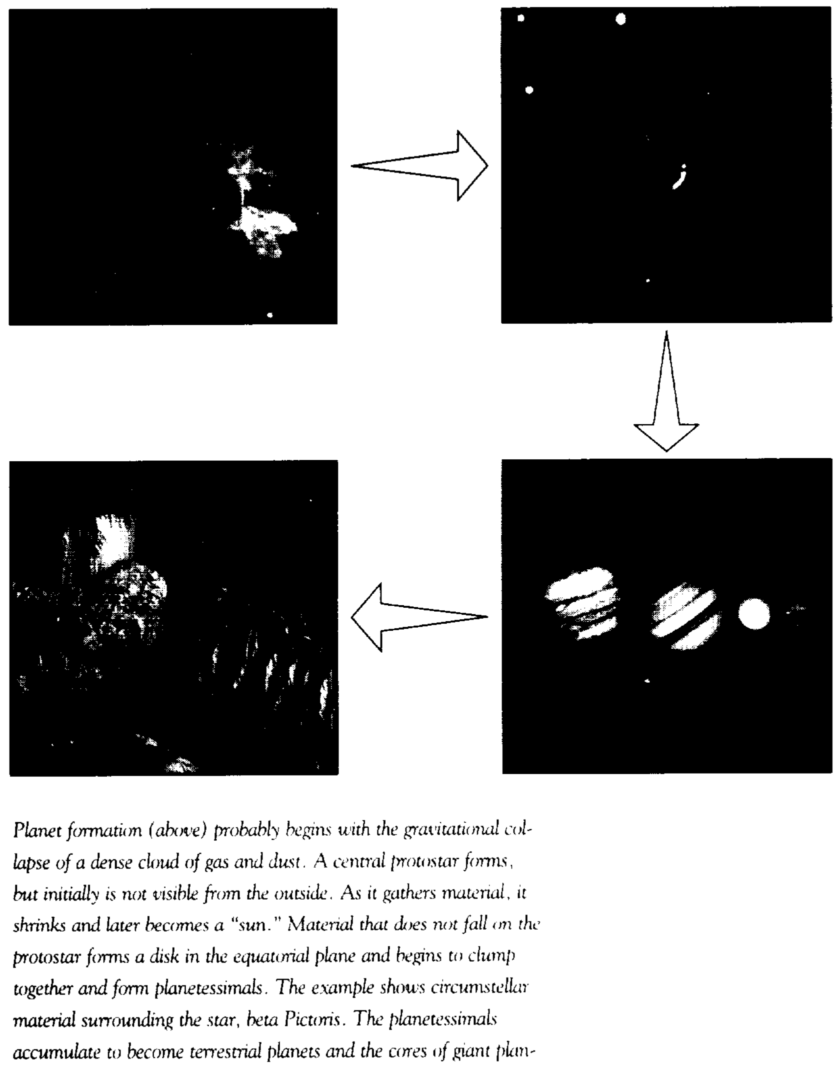
Our science goals are to:

Examine the content, structure, origin, and evolution of the galaxy and the universe. In the long term (25 to 50 years), we seek to answer the fundamental questions using observatories covering the entire electromagnetic spectrum In the near term (next 10 years), we will

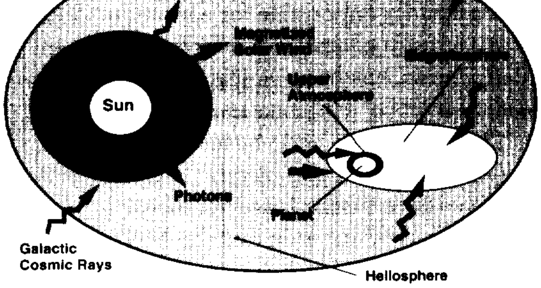
(1) complete the development of an initial observational capability across the electromagnetic spectrum, (2) complete the survey of cosmic rays and interstellar gas as samples of extrasolar matter, and (3) carry out basic new tests of gravitational theory.

Understand the relationship among the Sun, Earth, and heliosphere. In the long term, we will work to determine how the Sun creates high-energy radiation, large-scale particle eruptions, and the solar wind, and how these connect the Sun to the Earth and the galaxy. In the near term, we will (1) complete the means to understand mechanisms of solar variability and its effects on Earth, (2) determine plasma environments of solar system planets and their changes with solar activity, and (3) complete the first exploration of the inner and outer frontiers of the heliosphere.

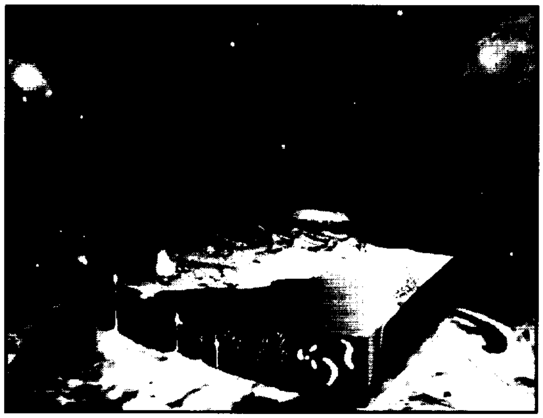
Understand the origin and evolution of planetary systems. In the long term, we seek to survey and sample the most important and accessible planets and small bodies in the solar system and to identify habitable planets around other stars. In the near term, we will (1) complete reconnaissance of the entire solar system from the Sun to Pluto, (2) conduct orbital surveys and begin surface exploration of the most fascinating and accessible planetary bodies, (3) begin a comprehensive search for planets and planetary formation around other stars, and (4) complete the inventory of near-Earth objects down to 1-kilometer diameter.



Planet formation (above) probably begins with the gravitational collapse of a dense cloud of gas and dust. A central protostar forms, but initially is not visible from the outside. As it gathers material, it shrinks and later becomes a "sun." Material that does not fall on the protostar forms a disk in the equatorial plane and begins to clump together and form planetessimals. The example shows circumstellar material surrounding the star, beta Pictoris. The planetessimals accumulate to become terrestrial planets and the cores of giant planets. The residual gas and dust dissipate, either blown away by stellar winds or accreted onto the planets that remain. Processes alter the characteristics of the primordial bodies, as shown in this example of landslides within Mars' Valles Marineris.



The Sun itself (left), a subject of intense study as our nearest star, creates and drives many solar system phenomena through its outputs of electromagnetic energy, energetic particles, and solar wind. These outputs affect Earth's magnetosphere, ionosphere, and uppermost terrestrial atmosphere. The solar wind itself carves out a huge bubble in interstellar space called the heliosphere. Cosmic rays as well as neutral atoms and dust are constantly entering the solar system by crossing the boundary of the heliosphere, carrying information about our galaxy and universe even as they undergo alterations in their encounter with the Sun's outflow of mass and energy.



The central figure shows chemical evolution processing from simple chemicals, to DNA, to microorganisms. On early Earth, this progression from primordial compounds to life could have been enabled by lightning, hydrothermal vents, and/or cometary impacts. We think this process is intrinsically connected to planetary evolution and is common in the universe. (Composite NASA and Scientific American, February 1991. Adapted from "In the Beginning . . ." by John Horgan. Copyright 1991 by Scientific American, Inc. All rights reserved.)

Understand the origin and distribution of life in the universe. In the long term, we will search for evidence of past or current life in the solar system and for evidence of inhabited planets and life elsewhere in the universe. In the near term, we will (1) determine the abundance and distribution of biogenic compounds conducive to the origin of life and (2) identify locations where conditions conducive to life have existed in the past or present.

EDUCATION AND PUBLIC OUTREACH

"The Space Science Enterprise uses its knowledge and discoveries to enhance science, mathematics,

Space Science's extensive use of advanced technology is an ideal vehicle for enhancing the scientific and technological skills of teachers. Here teachers participate in a satellite operations class at the Center for Extreme Ultraviolet Astrophysics, University of California–Berkeley.

and technology education, and the scientific and technological literacy of all Americans." Although the mission of the Space Science Enterprise is first and foremost to plan and carry out a world-class program of scientific research, it is clear that the Enterprise must contribute to larger national objectives as well. Many of the contributions needed are detailed in the President's science policy, *Science in the National Interest*. In particular, global economic competitiveness and sustained leadership in science and technology depend on greater public literacy in science, mathematics, and technology, as well as on the production of scientists, technologists, and engineers to meet the number and diversity workforce needs of the next century.

Space Science has a powerful capability to contribute in these areas. It has given us new eyes with which to view the universe and has opened new worlds to exploration. Space Science engages people's imaginations and fosters interest in science, engineering, and exploration. To take advantage of this, we are making education at all levels and the enhanced public understanding of science integral parts of all Space Science research, both ground- and space-based.

Our education and public outreach mission is to use our knowledge and discoveries to enhance science, mathematics, and technology education and the scientific and technological literacy of all Americans. We do so by clearly communicating the results of our missions to the public and applying the special talents of the Space Science community to improving science, mathematics, and technology education nationwide.

We also seek to support the efforts of organizations primarily responsible for education. Great investments in educational reform, curriculum development, teacher training, and the development of science, mathematics, and technology standards are being made by individual states and school districts and by other agencies within the U.S. Government (particularly the Department of Education and the National

Science Foundation). The Space Science community must meet three challenges to be effective in enhancing these larger efforts. First, space researchers must be aware of and understand national developments in education. Second, they must be aware of and sensitive to the needs of the education community. And third, they must identify those areas where the talents and capabilities of space scientists can be used most effectively and with the greatest leverage.

The education and public outreach goals of the Space Science Enterprise are to:

- Make significant and measurable contributions to meeting national goals for the reform of science, mathematics, and technology education, particularly at the K–13 level, and the general elevation of scientific and technological literacy throughout the country
- Contribute to the creation of the talented scientific workforce needed for the 21st century
- Promote the involvement of women, under represented minorities, and students with disabilities in Space Science educational programs and their participation in Space Science research and developmental activities
- Facilitate and cultivate strong and lasting partnerships on local, regional, and national scales between the Space Science research and development communities and the professional communities in science, mathematics, and technology education
- Share the excitement of Space Science programs and missions with the general public

Meeting these new responsibilities will require both a redirection of resources and the enthusiastic participation of the Space Science community in a range of education and public outreach activities that go well beyond its traditional role in undergraduate and graduate education. It must be understood *from the beginning* that incorporating education and public outreach into the planning and implementation of missions and research programs is an important part of what we do. Such efforts must be well focused, well coordinated, and carried out in collaboration with individuals who can supply critical expertise.

TECHNOLOGY

In technology, our mission is to develop, use, and transfer technologies that provide scientific and globally competitive economic returns to the Nation. This requires an early and sustained investment in key technologies. Among the objectives are reductions in mission life-cycle costs through reduced spacecraft and instrument mass, increases in mission capabilities, and reductions in operational complexity. These technologies will be developed through partnerships among NASA Centers, other Federal laboratories, universities, and industry. The Space Science Enterprise is committed to transferring technologies into the nonspace commercial marketplace to provide economic returns to the nation.

The technology goals of the Space Science Enterprise are to:

- Identify and support the development of promising new technologies that will enable or enhance space science missions and reduce mission life-cycle costs
- Infuse these technologies into space science programs in a manner that is cost effective, with acceptable risk
- Establish technology transfer as an integral element of the space science project life-cycle
- Develop strong and lasting implementing partnerships among industry, academia and government to assure that the nation will reap maximum scientific and economic benefit from its Space Science Program

Key Strategic Assumptions and Considerations

- The budget for Space Science will not increase, in real terms, for the foreseeable future, except for new Presidential initiatives.

- Space Science will continue to be an integral part of the national program of basic scientific research.

- Space Science is expected to make contributions that directly enhance the Nation's economic competitiveness and strengthen its educational systems.

- Coordinated efforts with other NASA offices, other Federal agencies, and not-for-profit and commercial/private organizations will be used to achieve the goals of the Space Science Enterprise.

- International cooperation in Space Science missions will continue to be a high priority.

- There will continue to be a viable U.S. industrial and academic base to support Space Science activities.

- Resources will be available to develop the new technologies needed for future Space Science missions.

- Launch vehicles appropriate for Space Science missions will continue to be available.

Principles

We strive to embody the values and principles stated here and in the NASA Strategic Plan to better serve the Nation. Our principles include:

- Emphasizing excellence as a measure of scientific leadership

- Maintaining the breadth of our scope of inquiry

- Emphasizing mission/program designs that maximize the development and dissemination of new technology relevant to broader national needs

- Pursuing basic scientific goals and strategies defined by the scientific community

- Accepting mission challenges; attempting that which is hard, not easy

- Learning from experience—innovating, persevering, and ultimately succeeding

- Executing programs with imagination, competence, and economy

- Using broadly representative peer review and advice in all aspects of the program

- Communicating openly with the scientific community, industry, Congress, the Administration, other Federal agencies, and the public

- Nurturing and enhancing the educational process to serve national goals

- Supporting universities to provide essential long-term research talent

- Using the best capabilities of industry and NASA Centers effectively in formulating and implementing the Space Science program

- Promoting international cooperation, where appropriate, in all our programs

- Using sound management practices with attention to equal opportunity and diversity, small disadvantaged business utilization, and the highest ethical standards of conduct

PROGRAM FORMULATION

THE NATIONAL ACADEMY OF SCIENCES AND SPACE SCIENCE ENTERPRISE PROGRAM PLANNING

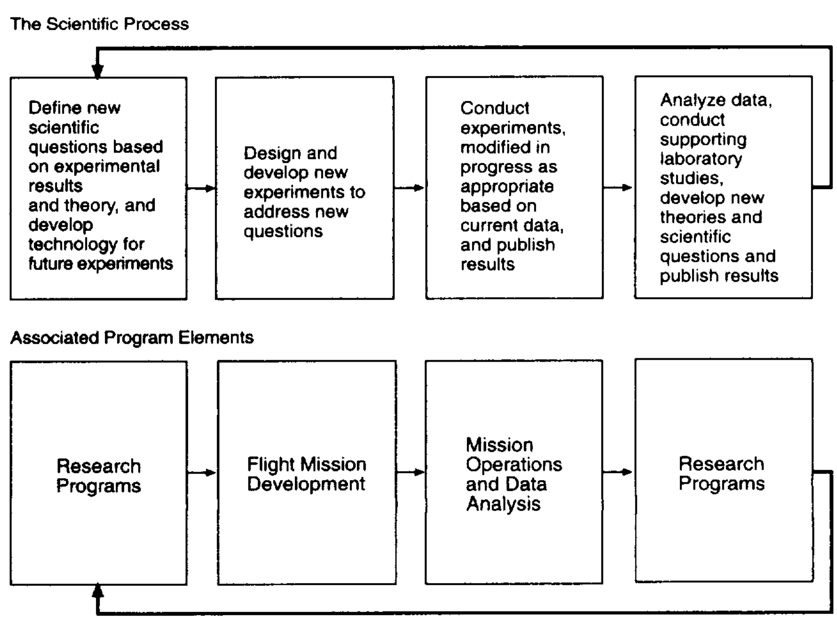
The scientific foundation for the Space Science Enterprise has been and continues to be developed by the National Academy of Sciences' National Research Council. Since 1958, a number of National Academy committees have critically assessed the status of various Space Science disciplines, identified the most promising directions for future research, outlined the capabilities required to address the most important scientific questions, identified areas where technology development is needed to attain those capabilities, and examined the role of each mission in the context of the total Space Science program. The Space Science goals and objectives, and all missions in the past, present, and future program, can be directly traced to the recommendations NASA has received from the National Academy.

In developing its program and mission strategy, the Space Science Enterprise has, in turn, examined the National Academy's recommendations, studied a number of options for obtaining the measurements required to address the prime scientific questions, and arrived at a set of specific missions intended to respond to the Academy's scientific strategies. The formulation and development of these missions has been monitored by the Space Science Advisory Committee, its three subcommittees, and numerous science working groups whose memberships are drawn largely from the non-NASA scientific community. The individual missions are also periodically reviewed by the Academy to ensure that they are responsive to Academy recommendations. This process ensures that Space Science missions meet the highest scientific standards and contribute to an overall strategy for scientific advancement with adherence to carefully considered priorities.

STRUCTURAL ELEMENTS

The scientific process involves a chain of events that begins with formulating specific scientific questions based on experiment, theory, and/or data analysis; designing and conducting experiments to address these questions; analyzing, interpreting, and disseminating the results of these experiments; and, finally, using the new knowledge to frame new scientific questions. Each Space Science program element—the Research Program; Flight Mission Development; and Mission Operations and Data Analysis—plays a unique and vital role in the process.

Space science structural elements mirror the scientific process.



The first element, the Research Program, has two major functions. The first is to support the analysis and interpretation of results from past missions, as well as data from related airborne, suborbital, and laboratory studies. This is accomplished in part through advanced information systems, which are essential to achieving our scientific objectives. This research yields the scientific questions that form the foundation of subsequent missions. The second function is to support the development of new technologies, information systems, and mission design concepts that prepare us to initiate new flight development projects.

The second element, Flight Mission Development, includes detailed mission definition; spacecraft and instrument design, development, testing, and integration; and launch support.

The third element, Mission Operations and Data Analysis, supports the operation of missions following launch and the analysis of data during the mission's operational lifetime. The Data Analysis component of this element is essential for evaluating the quality of the returned data, utilizing the capabilities of our spacecraft to capitalize on current discoveries and insights, and providing the first scientific returns from our missions.

Finally, the results of flight missions are published and disseminated, as well as incorporated into the Research Program for detailed analysis, comparison, and amplification through other research tools. This understanding and progress complete the cycle of the scientific process, paving the way for future inquiry and experiment.

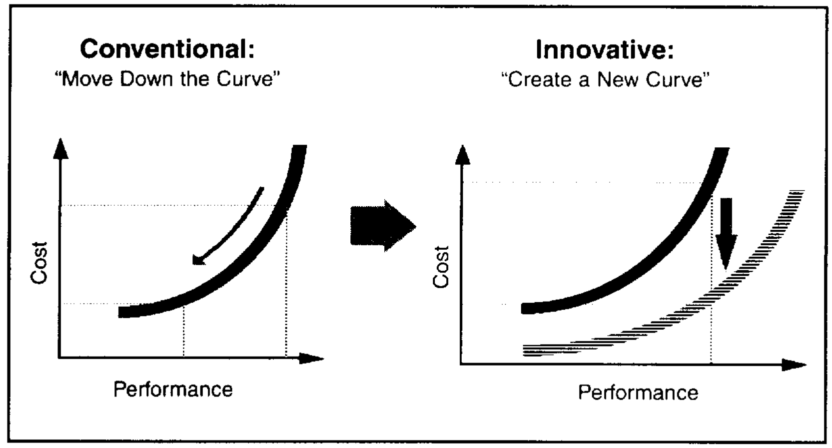
Environmental Assessment and Response

Changing Environment

Over the past few years, the climate in which the United States and NASA operate has changed significantly. The Cold War with the Soviet Union has ended, yet the United States finds itself in the midst of vigorous global competition. There are also increased domestic demands on Federal resources. As a result, NASA and the Nation have come under increased pressure to adapt to the changing environment. Maintaining competitiveness, providing value to America, and adapting to declining budgets while maintaining excellence are the main issues currently shaping NASA's strategic planning.

With the end of the Cold War, the United States has focused more on its economic position with respect to other nations. Increased foreign competition has prompted Americans to scrutinize the ways they do business. National priorities have shifted to the economy and related areas, such as education and technology development. New approaches are being sought to prepare our Nation economically for the next century. In this vein, Americans are demanding better performance from the Federal Government. Like other Federal agencies, NASA is being called on to emphasize the direct contributions it can make to the well-being of all Americans. Space Science missions, like other NASA programs, are being examined for the contribution they can make to improving U.S. competitiveness.

At the same time, the budget climate within which the Space Science Enterprise operates has changed drastically. The period of fiscal years 1986 through 1991 was one of double-digit annual growth for NASA as a whole, and Space Science maintained a relatively constant proportion of the NASA budget. The major missions currently under development were approved during this period. The period of fiscal years 1992 through 1994 has been one of transition, in which earlier expectations of growth that formed the basis for program planning were not realized. The consequences were dramatic: approved programs were canceled or drastically restructured, losses were experienced in supporting programs, and plans for new missions were not realized. The situation is now becoming even more severe. Space Science budgets are expected to decline for the rest of this century. New strategic approaches are necessary if we are to continue to make progress in this changing environment.



An innovative approach is to create a new cost-performance curve.

Strategic Actions: The Creation of a New Cost-Performance Curve

To accomplish our goals in an era of declining budgets, we must reduce costs dramatically while at the same time continuing to conduct a frontier Space Science research program. In terms of a cost-performance curve, there are two approaches. "Move down the curve" will force us to respond to declining budgets with ever-decreasing levels of performance. "Create a new curve" for which a given performance level can be achieved at lower cost is imperative if we are to meet the scientific challenges of the future.

Many actions will be necessary to create and realize the benefits of a new cost-performance curve. Some have already been initiated, and others must be added. We must explore new conceptual approaches to missions, streamline management, introduce new technologies, and increase the investment in mission definition prior to development. The following specific strategic actions will contribute toward the creation of a new cost-performance curve and, in doing so, will free resources for application to future programs.

Reduce the Costs of Missions in Development

With decreased budgets and pressure to do more with less, all Space Science missions have had to be restructured. Recent notable examples—Cassini, AXAF, and FUSE—have been successfully restructured to reduce both life-cycle cost and peak-year spending while maintaining major mission goals. Cost caps for all other missions in development have been established that are consistent with new NASA policy. A primary objective is to minimize life-cycle costs in all our current and future programs.

Reduce the Costs of Operating Missions

Savings have been achieved by re-engineering mission operations. Efficiencies and new, innovative approaches to mission operations will be continually sought to free resources for new future missions. Among the actions being taken and/or examined are:

- Streamlined, paperless procedures for operations planning
- Consolidation of control and data handling centers to achieve efficiencies through shared equipment, software, and expertise

- Use of common software and hardware, beginning with mission development and integration and continuing during flight operations

- Applications of new technologies to achieve more autonomous, less labor-intensive operations

Furthermore, all missions in the extended phase of their operation will be reviewed for scientific productivity and prioritized each year in competition with new starts so that maximum science benefit can be achieved with limited resources.

Continue to Direct the Definition of New Flight Programs to Less Costly Missions

Space Science has moved away from the costly spacecraft of the past and now focuses on developing technology for more efficient, lower cost spacecraft. We are focusing new mission studies on less costly options, defining cost as a significant constraint early in mission definition, and more precisely defining mission science objectives so as to contain costs. Current examples include the Discovery, the Surveyor, and the restructured Explorer programs. This ensemble of low-cost missions has to be phased to fit into a stable level-of-effort budget without the large funding "spikes" characteristic of large missions. With these programs and all others, we are renewing our emphasis on looking for opportunities to collaborate with other agencies, private industry, and international partners to reduce costs and avoid duplication, and we are continually searching for lower cost launch options. In this regard, we will restructure and reinvigorate the Suborbital and Small Payloads Program to incorporate new techniques for providing low-cost access to space, such as long-duration balloons, launches by ultralight expendable launch vehicles (ELV's), and launches of secondary payloads by small and medium ELV's.

Provide for Continuing Investment in Technologies for Future Missions

Maintaining an early and sustained technology development investment in a constrained budget environment has traditionally been difficult. Too often, the temptation to apply all resources to address near-term needs becomes overpowering. However, the current environment—with its certainty of increasingly constrained fiscal and physical resources—illustrates the importance of establishing a focused process for aggressive technology development and infusion into Space Science missions.

To this end, the Space Science Enterprise has recently taken actions in several key areas. It has established a policy requiring that each Space Science mission contribute to the advancement of spaceflight technology for future missions, and the Enterprise has reflected this in its Research Announcements. It has partnered with the Space Technology Enterprise to establish flight system testbeds for rapid prototyping and testing of new instruments and subsystems. In addition, to ensure its ability to move boldly into the next century with frequent launches of low-cost, capable "sciencecraft," it has spearheaded NASA's New Millennium Program. The New Millennium Program will provide a framework within which NASA's Space Science, Mission to Planet Earth, and Space Technology Enterprises will form partnerships with industry, academia, and other government agencies to aggressively develop and qualify revolutionary new technologies for spaceflight.

Seek International Cooperation on New Flight Programs

The Space Science Enterprise is now more than 35 years old, and since its origin it has been pursued as an international enterprise. The last 15 years have seen an increasing level of international cooperation on U.S. missions in many forms—the participation of foreign scientists, the accommodation of scientific instruments or subsystems, the provision of tracking and navigation services, and the provision of launch services. Similarly, U.S. scientists and U.S.-provided instruments and services have been playing an increasingly important role on non-U.S. missions. Some missions, such as Cassini and the

Solar and Heliospheric Observatory (SOHO), have been carried out as joint projects. This latter style of cooperation has become ever more common as the worldwide resources available for space science projects have become more scarce. International partnerships have been secured on the Stratospheric Observatory for Infrared Astronomy (SOFIA), an infrared astronomy cooperative program with Germany; Astro-E, an x-ray astronomy mission by Japan's Institute for Space and Astronautical Science; and Rosetta-Champollion, a European Space Agency comet rendezvous mission. The Space Science Enterprise is currently pursuing international cooperation with Japan on the Space Infrared Telescope Facility (SIRTF). Expanded cooperation with our traditional partners and the forging of new partnerships will expand space exploration opportunities and promote the peaceful uses of technology while reinforcing economic and technological bonds in the new global society.

Sustain the Research Program

As noted earlier, the Research Program in Space Science provides support for the science community to analyze and interpret results from past missions as well as data from related airborne, suborbital, laboratory, and theoretical studies. It also supports the development of new technologies, information systems, and mission design concepts. Thus, the Research Program delivers the ultimate products of Space Science and exploration and helps set the stage for the future. The Research Program is therefore an absolutely central element, forming the foundation for virtually everything that the Space Science Enterprise does. It has been evolving to ensure that it matches our scientific strategy. In a declining budget environment, difficult choices must be made in funding research programs to make room for new results, new subdisciplines, and new initiatives.

Work to Secure a Stable Budget Environment

Our efforts to reduce development and operations costs are critical for the Enterprise to sustain a viable program within the declining resource envelope. Ultimately, however, our success greatly depends on securing a stable budget. Although many of the factors that determine the overall fiscal environment are not in our control, a number of steps to secure a healthy future *are* in our control. In particular, we can:

- Demonstrate to the science community, the public, and government decision-makers that our programs are both relevant and important to the Nation
- Be selective in determining our objectives
- Deliver on the promises we make, and successfully bring our programs to completion
- Provide for broad, timely dissemination of our results in an understandable form
- Use public interest in our program to foster a scientific and technologically literate society
- Make demonstrable contributions to the advancement of technologies critical to enhancing the economic strength of the United States

Develop Program Metrics

Metrics are important tools for determining how well we are achieving our goals and serving the needs of our customers. Different phases of flight programs require different types of metrics. When missions are competing for initiation, metrics must measure overall value and cost effectiveness. When missions are in development, metrics focus on performance relative to planned cost and schedule and the capability to achieve the mission's scientific and technical objectives. During operations, metrics are applied to operational efficiency and the degree to which goals are being met and public benefits derived. Post-mission metrics center on objectives and public benefits, as do the metrics for the Research Program. The use of these metrics helps ensure a continuing focus on the cost-benefit ratio for all programs.

STRATEGY

SCIENCE

As discussed in the previous section, declining budget expectations for Space Science require that we fundamentally alter our approach to future missions. Individual spacecraft have been made smaller to reduce spacecraft development as well as launch costs. Mission operations procedures are being critically reevaluated. Large spacecraft have been broken into multiple, small spacecraft to distribute risk and reduce cost. The introduction of new technologies has been made an integral part of all future programs. Heightened attention is being paid to the broad dissemination of those technologies and to the identification and development of educational opportunities associated with all missions.

Scientifically, the current and future programs are designed to make significant advances across all four themes.

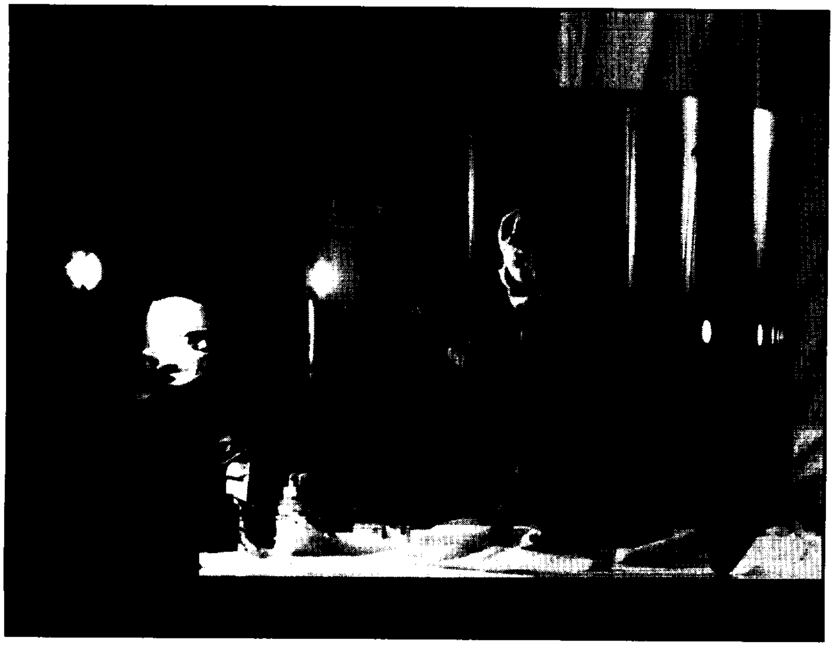
THE GALAXY AND THE UNIVERSE

Current Programs

The first two Great Observatories, the Hubble Space Telescope (HST) and the Compton Gamma Ray Observatory (CGRO), are both fully operational. The numerous, major scientific discoveries from these two space observatories are revolutionizing our understanding of the universe. The Extreme Ultraviolet Explorer (EUVE) has revealed large anisotropies in the hot interstellar medium in the Sun's vicinity, allowing even extragalactic extreme ultraviolet sources to be observed. The Cosmic Background Explorer (COBE) spacecraft has confirmed the Big Bang theory of the origin of the universe and has revealed structure in the remnant radiation that explains the birth of galaxies in the early universe.

Space Science	Flight Programs		
	Ongoing	In Development	Future
Milky Way Galaxy and the Universe	HST CGRO EUVE KAO (Voyager)	AXAF GP-B SWAS XTE FUSE	SOFIA SIRTF Future Explorers (Solar Probe)
Sun-Earth-Heliosphere Connection	SAMPEX Ulysses Wind Yohkoh Voyager (CGRO)	ACE Polar FAST SOHO	Solar-Terrestrial Probes Solar Probe Future Explorers
Planetary Origin and Evolution	Galileo (KAO, HST)	Cassini NEAR Mars Pathfinder Mars Global Surveyor	Mars Surveyor Future Discovery Missions Pluto Express (SOFIA, SIRTF)
Origin and Distribution of Life in the Universe	(Galileo, KAO)	(SWAS, Cassini, Mars Pathfinder, Mars Global Surveyor)	(Mars Surveyor, Future Discovery Missions, SOFIA, SIRTF)

In this chart on the current and future Space Science Program, missions appear without parentheses under the themes they primarily address. Some appear again with parentheses under a theme that is their secondary objective. International missions in which NASA has a major involvement are included. Acronyms are defined in the Appendix.



Quality inspectors perform a visual inspection of the P1 (Parabola 1) optic for NASA's Advanced X-ray Astrophysics Facility (AXAF). P1 measures 1.2 meters in diameter by 1 meter in length and weighs 520 pounds. The wall of the optic is only nine-tenths of an inch thick. All eight AXAF mirrors were completed ahead of schedule in December 1994. An end-to-end x-ray test of AXAF will be conducted in January 1997. (Hughes-Danbury Optical Systems)

Approved flight programs in development, including the Advanced X-ray Astrophysics Facility (AXAF), Gravity Probe B (GP-B), the Submillimeter Wave Astronomy Satellite (SWAS), the X-ray Timing Explorer (XTE), and the Far-Ultraviolet Spectroscopy Explorer (FUSE), will probe the laws of physics in the vicinity of the most energetic sources in the universe, will determine the structure of space itself, and will reveal the details of the interstellar medium from which stars are born and to which they return after death.

Near-Term Future Programs (5 to 10 Years)

In the coming 5 to 10 years, the major focus of this theme will be to open the remaining window on the universe not exploited from space: the infrared. This window has come last because detector development was more challenging; that development is now well advanced. The importance of completing a full picture of the universe is so great that the only priority in this theme is to undertake missions in infrared astrophysics. Two programs are proposed: the Stratospheric Observatory for Infrared Astronomy (SOFIA) and the Space Infrared Telescope Facility (SIRTF).

The Stratospheric Observatory for Infrared Astronomy (SOFIA)

SOFIA represents a major increase in capabilities over the highly successful, but aging Kuiper Airborne Observatory (KAO). SOFIA will be used to study star and planet formation, the dynamics and chemistry of the interstellar medium, galactic structure and evolution, and the Sun and other solar system bodies. The mission consists of a 2.5-meter infrared/submillimeter telescope that will be installed in a modified Boeing 747

SOFIA will directly involve K-12 teachers and students with scientists and engineers through a series of meaningful educational partnerships, stimulating interest in mathematics, science, and engineering. (NASA Ames Research Center) aircraft and operated at altitudes above 40,000 feet. Because of its mobility and the fact that nonspecialists can fly on a SOFIA mission, this will be the only NASA program in which educators can actively participate as flight members with scientists and engineers. This will build on the highly successful, beneficial experience that many K–12 teachers have had on the KAO.

Space Infrared Telescope Facility (SIRTF)
The Space Infrared Telescope Facility (SIRTF) will take advantage of recent spectacular advancements in infrared sensor technology to build on the technical heritage of two of Space Science's most successful missions, the Infrared Astronomical Satellite (IRAS) and the Cosmic Background Explorer (COBE). The SIRTF mission has been vastly simplified from its original design through a focusing of its scientific objectives and the use of innovative design techniques. This has resulted in significant reductions in life-cycle costs.

SIRTF and SOFIA are complementary programs. Both are essential for exploiting the infrared region of the spectrum. The SOFIA science program will capitalize on spatial and spectral resolution, while the SIRTF science goals make use of its excellent sensitivity and large detector arrays.

Long-Term Future Program (10 to 25 Years and Beyond)
Beyond these missions, this theme will develop revolutionary technologies designed to probe our discoveries about the universe in ever-increasing detail. Space interferometers will make it possible to image planetary systems around other stars, to image the hot gas falling toward black holes, and to measure full three-dimensional motions of stars and galaxies. Very large telescopes will collect detailed spectroscopic and imaging information from gamma rays through microwaves to understand how the universe transformed from the hot gas of the Big Bang to the galaxies of today.

SIRTF will be able to peer through the dust in our galaxy, providing us with a view of the center that would otherwise be unavailable. The optical image is on the left; the infrared is on the right. (Infrared Processing and Analysis Center)

SUN-EARTH-HELIOSPHERE CONNECTION

Current Programs
The Voyager 1 and 2 and Pioneer 10 and 11 spacecraft will be humankind's first spacecraft to leave the solar system. Moving in different directions relative to the motion of the Sun through the galaxy, they are exploring the outer regions of the heliosphere, searching for the solar wind termination shock and the heliopause.

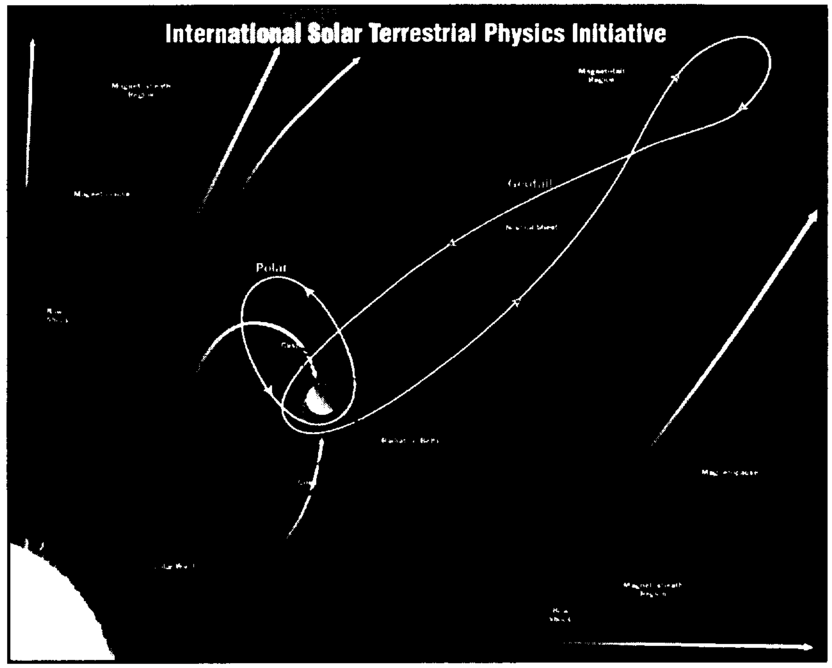
The joint NASA-European Space Agency (ESA) Ulysses spacecraft has completed its passage over the Sun's south pole and has crossed the ecliptic plane on its way to the north polar region, exploring for the first time these out-of-the-ecliptic frontiers of the inner solar system. The polar source regions of the corona and solar wind are also being viewed during each polar pass by coronagraphs on Spartan-201, which was launched and retrieved by the Space Shuttle. X-ray studies of the solar corona by a NASA-provided investigation on the U.S.-Japan Yohkoh mission have revealed continuous violent activity—a vivid contrast to the subtle visible luminosity variations on the underlying disk of the Sun. These dynamic events will be captured in much higher time resolution by the Transition Region and Coronal Explorer (TRACE), beginning in 1997.

Unprecedented, coordinated studies of global geospace phenomena have begun from a series of satellites being placed in key regions between the Earth and the Sun under the International Solar-Terrestrial Physics (ISTP) Program. Two

NASA spacecraft in the ISTP initiative are Wind and Polar. Wind was launched in November 1994, and Polar is scheduled for a December 1995 launch. Wind's primary role is to measure particles and fields in the solar wind prior to their impacting the Earth's magnetosphere. Polar will measure the flow of magnetospheric plasma along geomagnetic field lines and image the deposition of particle energy into the ionosphere and upper atmosphere with unprecedented resolution. The ISTP Program includes three additional missions: Geotail (NASA-Japan), launched in 1992, and the Solar and Heliospheric Observatory (SOHO) and Cluster missions (both NASA-ESA), to be launched in 1995. Geotail has explored the geomagnetic tail at great distances and is now nearer to the Earth. Cluster consists of four coordinated spacecraft that will resolve the smaller scale spatial structures and turbulence in three dimensions at various locations in the magnetosphere and the solar wind. SOHO will study the interior dynamics of the Sun and features of the solar corona that result in an energized solar wind. ISTP will enable cause-and-effect determination of events starting at the Sun, propagating in the solar wind and transferring energy, mass, and momentum to the magnetosphere and ultimately to the Earth's upper atmosphere.

NASA is a participant in the National Space Weather Program (NSWP), an interagency initiative rooted in space research and designed to provide timely, accurate, and reliable space environment observations, specifications, and forecasts. NASA's missions in Space Physics, particularly the ISTP Program, contribute fundamentally to the NSWP.

Near-Term Future Programs (5 to 10 Years)
Near-term future programs will build on the accomplishments of the ISTP Program. The lead missions, the Solar Terrestrial Probes series and the Solar Probe, offer compelling scientific breakthroughs and new technological accomplishments. These will be complemented by NASA contributions to foreign-led missions.



The heart of the program is the quest to understand the mechanisms of solar variability and to elucidate the processes linking the Sun, the heliosphere, and the Earth's upper atmosphere and magnetosphere.

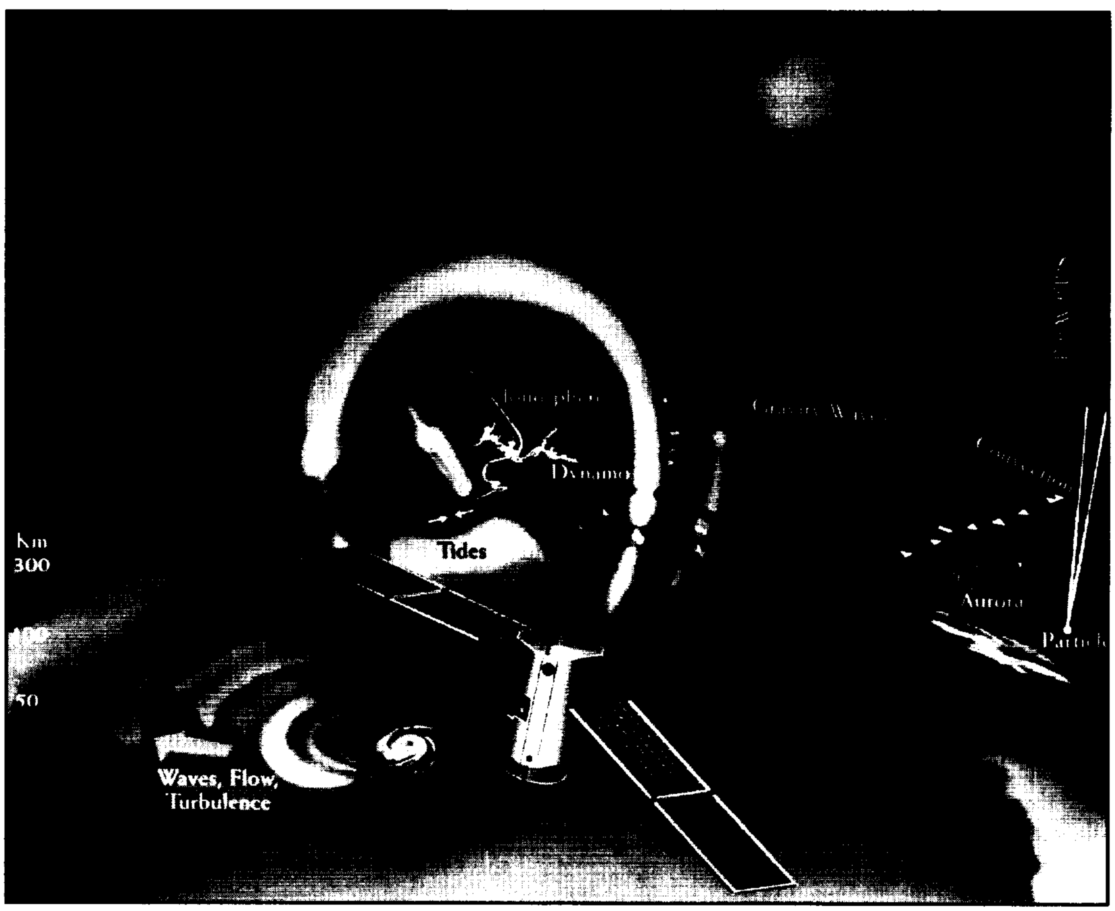
There is a growing international effort to understand the Earth's global space environment. The International Solar Terrestrial Physics (ISTP) Program was established to better understand the interaction between the solar wind and the Earth, and it will eventually involve as many as six simultaneous spacecraft.

Solar Terrestrial Probes
The Solar Terrestrial Probe series will employ small spacecraft (typically costing less than $100 million for spacecraft and instruments) for highly focused studies addressing critical problems in solar variability and its influences. The planned program will study three critical types of Sun-Earth-heliosphere connections:

- *Low-Energy Radiation Connection*: This is an investigation of the connection between the variable ultraviolet and extreme ultraviolet radiation from the Sun and the response of the Earth's mesosphere/lower thermosphere—the outermost layer of the Earth's atmosphere. A single small satellite, the Thermosphere, Ionosphere, Mesosphere Energetics and Dynamics (TIMED) mission, will measure the variability of the ultraviolet/extreme ultraviolet output of the Sun and use remote sensing techniques to probe the response of the Earth's mesosphere and lower thermosphere, over the altitude range from 60 to 180 kilometers.

- *High-Energy Radiation Connection:* This is an investigation of the generation of solar high-energy radiation and particles in flares. A small satellite called the High Energy Solar Imager (HESI) will use innovative technology to obtain images at wavelengths from x-rays to gamma rays, the highest energies released in flares. It is critical that HESI be operating during the period of maximum solar activity expected from 1999 through 2002. This mission is expected to fill in the heretofore missing observational boundary conditions that will allow discrimination among the competing flare theories.

- *Plasma Connection:* This is an investigation of the connection between the mass (plasma) ejections from the Sun and the global response (geomagnetic storms) of the magnetosphere. The Magnetospheric Imager (MI) will use innovative techniques to make the first images of the Earth's magnetosphere in both ultraviolet photons and particles (energetic neutral atoms). This will be the first direct view of the dynamically evolving magnetosphere in which Earth satellites operate. The variable input of solar plasma to the magnetosphere will be measured by the Advanced Composition Explorer (ACE) spacecraft currently under development for launch in late 1997.



The TIMED mission will investigate the energy input/output and the dynamics of the mesosphere and lower thermosphere, which are otherwise largely unexplored by space observations. (NASA Goddard Space Flight Center)

Solar Probe

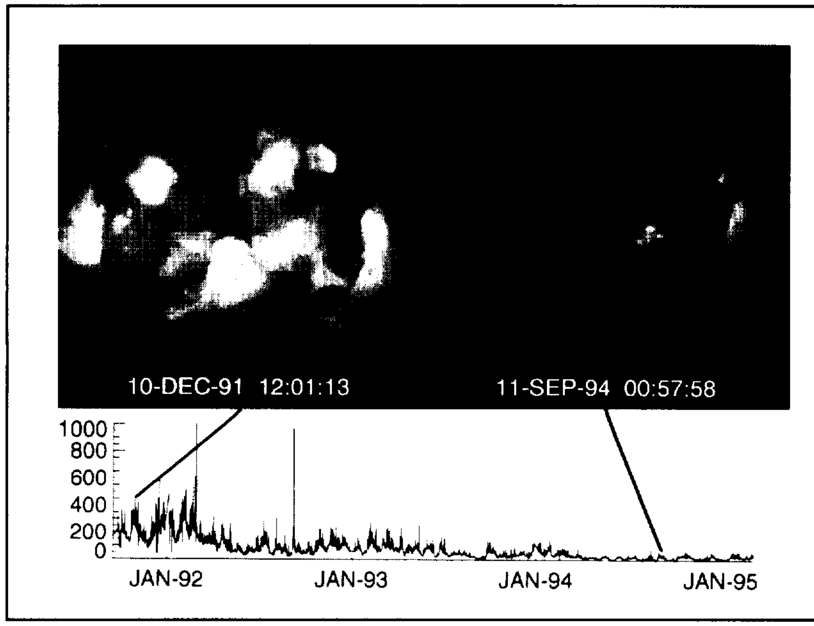
The Solar Probe will be our initial close reconnaissance mission to the largest unexplored solar system body—namely, the Sun itself. Passing within 3 solar radii of the Sun's surface, this mission will address long-standing fundamental questions about the connection of the solar corona to the outflowing solar wind that fills the heliosphere. These questions include: What heats the solar corona?; What accelerates the solar wind?; From where does the solar wind come?; and What mechanisms accelerate, store, and transport energetic particles?

Long-Term Future Programs (10 to 25 Years and Beyond)

Beyond these missions, we will continue to explore the space environment from the Sun to the galaxy and around the planets, especially the Earth, with dual goals: (1) to achieve a thorough scientific understanding of the space environment and its "weather" as a basis for safe, substantial long-term human and robotic access to space and (2) to understand the relationship of a star and a planetary system in which life has arisen and will die, along with the galaxy in which they were born.

The Interstellar Probe will be a small fast spacecraft specifically designed to leave the solar system and remotely sample the local interstellar cloud enveloping the solar system in a decade or less, to look for prebiotic organic molecules and other constituents from which stars and planetary systems form. On its way, the Interstellar Probe would characterize how this cloud stops our solar wind and how the energy of the solar wind is dumped into the local interstellar cloud.

Longer term Solar Terrestrial Probes may include the Special Perspectives Investigation (SPINS)—twin spacecraft providing stereoscopic views of the Sun and maps of the evolution of coronal mass ejections and other disturbances—and the Maxwell mission—designed to resolve competing theories of fundamental plasma transport and energization that takes place at magnetospheric boundary layers.



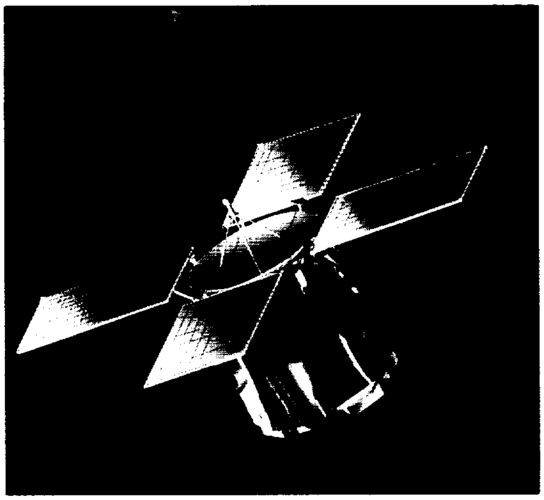
The images of the Sun come from the joint U.S.-Japanese Soft X-ray Telescope (SXT) on the Yohkoh satellite. The Yohkoh mission is a program of the Japanese Institute of Space and Astronautical Science (ISAS) and NASA. These two Yohkoh images capture the x-ray brightness of the Sun at different times in the solar cycle. The image on the left was taken on December 10, 1991, during a period with many active regions; the image on the right was taken in 1994 during a period with fewer regions (the level of total x-ray brightness is also shown on the graph along the bottom of the images). The Sun's variability over time has direct impacts on electronics, communications, and power systems in space and here on the Earth.

PLANETARY SYSTEM ORIGIN AND EVOLUTION

Current Program

The Galileo spacecraft has conducted the first-ever asteroid flybys of Gaspra and Ida, discovering Dactyl, a moon of Ida. The spacecraft is now on its way to a rendezvous with Jupiter in December 1995 to conduct a comprehensive study of the Jovian system. The face of Venus has been revealed at high resolution for the first time by the Magellan spacecraft. More than 99 percent of the surface of this perpetually cloud-covered planet has been mapped at 120-meter resolution by radar, revolutionizing our understanding of terrestrial (that is, Earth-like) planets.

Artist's concept of the Near Earth Asteroid Rendezvous (NEAR) spacecraft. NEAR will launch in February 1996 as the first of the Discovery series. (NASA/JPL)



The Discovery Program responds to NASA and congressional imperatives to develop small planetary missions that can be built and flown by the science community in a very short time span (3 years or less from new start to launch) and at low cost. Discovery will provide frequent access to space to address focused science objectives and opportunities to explore emerging planetary science disciplines. It will also provide opportunities for university and student involvement and for new technology infusion and transfer that cannot be attained in larger and lengthier programs. The first Discovery mission, Near-Earth Asteroid Rendezvous (NEAR), will launch in 1996 to rendezvous with the Earth-approaching asteroid 433 Eros in early 1999. It will orbit Eros for a year, making comprehensive quantitative measurements of the asteroid's composition and structure. The second Discovery mission, Mars Pathfinder, will land on the surface of Mars in 1997 to test an innovative entry, descent, and landing system; investigate atmospheric structure and surface meteorology, geology, and elemental composition; and deploy and test an experimental microrover. We subsequently expect to launch a Discovery mission approximately every 18 months.

The Mars Surveyor Program is a small-spacecraft, innovative approach to both recovering from the tragic loss of the Mars Observer and resuming the surface exploration of Mars. The program begins with the Mars Global Surveyor orbiter, to be launched in 1996, carrying all but two of the Mars Observer instruments. The next step is two small spacecraft—an orbiter and a lander—to be launched in 1998 to help scientists trace the evolution of the planet's climate and search for water in the Martian soil. Ground-based observational work continues to add significantly to our understanding of planetary systems. Recent highlights include the discovery of Comet Shoemaker-Levy and observations of the spectacular impacts of its fragments with Jupiter in July 1994, as well as radar observations of 4769 Castalia, a "double" near-Earth asteroid. The comet impacts were also recorded by instruments on the Galileo spacecraft, as well as a variety of other platforms, including the Hubble Space Telescope and the Kuiper Airborne Observatory.

Cassini/Huygens, the last of a class of "flagship" missions still in development, will conduct a comprehensive investigation of the Saturnian system beginning early in the next century. The Cassini spacecraft will carry 18 instruments to study Saturn's atmosphere, rings, magnetosphere, and satellites during a 4-year tour. The ESA-developed Huygens probe will enter the smoggy atmosphere of Titan, Saturn's large moon, to directly investigate both the atmosphere and surface.

Near-Term Future Programs (5 to 10 Years)

The planning for missions to study our planetary system has undergone a dramatic restructuring, from an earlier emphasis on comprehensive, but large and infrequent missions to an emphasis on frequent, small, focused, low-cost missions using small launchers. This restructuring is already apparent in the current program, particularly in the first missions of the Discovery Program and the Mars Surveyor Program described above. The future programs in this theme continue this restructuring, maintaining the highest level of scientific quality using small, innovative spacecraft.

Artist's conception of the Cassini orbiter and probe. (NASA/JPL)

Discovery Program

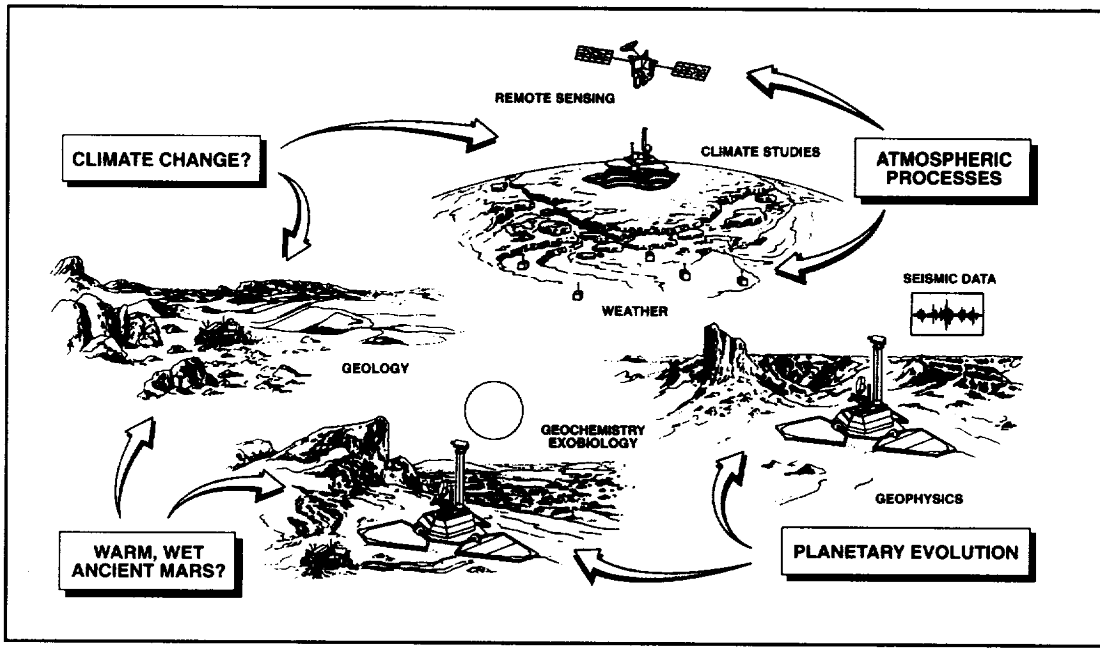
The third Discovery mission will be the Lunar Prospector, which will conduct low-altitude mapping of lunar surface composition, magnetic field, gravitational field, and gas release events to improve our understanding of the origin, evolution, current state, and resources of the Moon. The fourth Discovery mission will be selected from among three missions now undergoing Phase A studies: Suess-Urey, a mission for returning solar wind ions for isotopic and chemical analyses to improve our knowledge of solar isotopic and elemental abundances; Stardust, a mission aimed at collecting and returning cometary dust and interstellar materials for laboratory analysis to help us better understand primitive bodies; and Venus Multiprobe, a mission for measuring detailed wind and temperature profiles by means of 16 small probes to understand the mechanisms driving the atmosphere's superrotation.

Mars Surveyor Program

This program will continue beyond 1998, using orbiters and landers to take vital steps toward our long-range goals for Mars exploration. These goals are to determine whether life ever began on Mars and, if so, in what form; to better understand the climate history of the planet; to determine the mode of formation and evolution of the solid planet; and to determine the availability of resources. These spacecraft will deliver to the Martian surface a new generation of miniaturized science instruments for a wide range of surface and subsurface investigations. The program will culminate in a sample return mission, possibly as early as 2005.

Pluto Express

A voyage of discovery to the only remaining unexplored planet, Pluto Express will meet severe cost constraints through limits to its scientific objectives and incorporating new technologies. The mission is critical if the United States is to retain its capability for conducting long-lived deep space exploration—we are the only nation on the Earth to demonstrate this extraordinary technological skill. Pluto Express scientific goals include intercomparing the cryogenic Titan-Triton-Pluto triad, which rivals the Venus-Earth-Mars triad in complexity; studying Pluto's unique atmosphere, which builds up and decays like that of a comet during each orbit about the Sun; studying the chemistry of the outer solar nebula; and studying the formation of the unique Pluto-Charon binary. The current baseline calls for two identical spacecraft to be launched around the year 2003.



The Mars Surveyor Program addresses top-priority exploration objectives for Mars, including: life on Mars, past or present; climate history and implications for understanding the Earth's climate; sample return; and direct public involvement in exploring the unknown. The plan entails two launches to Mars every 26 months from 1996 to 2005; a fixed annual budget and mission cost caps; short development time; and advantageous use of the Mars Pathfinder experience (landing system and rover operations on Mars). (NASA/Jet Propulsion Laboratory)

Rosetta-Champollion

NASA participation in the ESA-led International Rosetta Comet Probe mission will also play an important role in the future program, recovering some of the science objectives from the canceled Comet Rendezvous/ Asteroid Flyby mission. NASA will provide the Champollion lander in collaboration with CNES, the French National Space Agency. The overall goals of the mission include characterizing the cometary nucleus globally; determining the chemical, mineralogical, and isotopic compositions of volatiles and refractories in the nucleus; and studying the development of cometary activity, including processes in the nucleus surface layer and the inner coma.

Long-Term Future Programs (10 to 25 Years and Beyond)

Beyond these missions, this theme will strive to continue advancing toward its long-range goals through such missions as probes to comets and asteroids, the Mercury Orbiter/Lander, the Venus Aerocraft/Lander, the Jupiter Polar Orbiter/ Satellite Landers, the Saturn Atmosphere Probe/Titan Surveyor Lander, the Uranus/ Neptune Orbiters/Probes, and the Kuiper Belt Objects Multiple Flyby. A particular emphasis will be comparative planetology: developing an understanding of how the manifestations of forces that shape planets vary in different planetary settings, including that of the Earth.

A major effort is also expected in a particular aspect of comparative planetology: the search for and characterization of planets orbiting other stars. These investigations will expand our understanding of solar system formation and evolution and determine whether solar systems like ours are common or rare in the galaxy. Two factors contributing to heightened activities in this area in the coming decades are (1) the steady accumulation of evidence—from several sources—of the existence of protoplanetary disks and of oscillations in the positions of some stars consistent with planetary perturbations and (2) rapidly advancing technological capability that makes these investigations feasible.

ORIGIN AND DISTRIBUTION OF LIFE IN THE UNIVERSE

Current Program

The only past Space Science mission designed specifically to address questions of the origin and distribution of life was the Viking mission to Mars. Nonetheless, many missions make major contributions to addressing questions encompassed by this theme. For example, Cassini's Huygens probe to Titan will provide photochemical data likely to refine our understanding of prebiotic chemical evolution. Galileo, in flying by Europa, will investigate the possibility that there is a liquid water ocean—a possible habitat for life—beneath that satellite's frozen surface. Current missions to Mars, Pathfinder and the first missions of Mars Surveyor, will contribute to critical information about the location and history of water, the quintessential ingredient of life. Subsequent missions to Mars will search for evidence of prebiotic evolution, ancient life, and—guided by earlier results—even for life on the planet today.

Near-Term Future Program (5 to 10 Years)

Among the future missions that will make contributions to this theme are the SIRTF, SOFIA, Mars Surveyor, and Discovery missions. SIRTF and SOFIA address the history of the biogenic elements (carbon, hydrogen, nitrogen, oxygen, phosphorus, and sulfur) from their birth in stars to their incorporation into planetary bodies. The six stages in this history are: (1) nucleosynthesis and ejection into the interstellar medium; (2) chemical evolution in the interstellar medium; (3) protostellar collapse; (4) chemical evolution in the solar nebula; (5) growth of planetessimals from dust; and (6) accumulation and thermal processing of planetoids. Each of these stages involves characteristic infrared emissions, which SIRTF and SOFIA are designed to detect.

The Mars Surveyor series and Discovery missions to primitive bodies will address questions of prebiotic evolution. The strategy is to investigate the planetary and molecular processes that set the physical and chemical conditions within which living systems might have arisen. The four major objectives are to: (1) determine constraints on prebiotic evolution imposed by the physical and chemical histories of planets; (2) develop models of active boundary regions in which chemical evolution could have occurred; (3) determine what chemical systems could have served as precursors of metabolic and replicating systems both on the Earth and elsewhere; and (4) determine in what forms prebiotic organic matter has been preserved in planetary materials. In addition, Mars Surveyor will shed light on the crucial link between planetary evolution and the origin of life itself.

Understanding the Sun-Earth-heliosphere connection, including solar variability and the Earth's response, will also allow us to better understand the complex interactions that maintain the environment for life on the Earth. This will in turn allow us to better understand the conditions necessary for sustaining life on other planets.

Long-Term Future Programs (10 to 25 Years and Beyond)

Beyond these missions, advances in this theme will be accomplished through missions such as Asteroid Landers/Sample Return, Comet Nucleus Sample Return, and Mars Sample Return.

Education and Public Outreach

Our education and public outreach strategy explicitly establishes a number of new directions for the Space Science Enterprise. In response to national goals, there is a special emphasis on precollege education and on developing introductory college courses aimed at raising students' broad understanding and appreciation of science. This direction does not diminish the importance of the traditional role of the Space Science Enterprise in supporting graduate and postgraduate professional education. Rather, it represents an expansion of our education role to meet pressing national needs.

Contributions to life-long education are also important components of such activities. To increase the public's knowledge, understanding, and appreciation of science and technology, we must expand our outreach activities beyond traditional classrooms and form partnerships with a wide range of institutions engaged in communicating science and technology to the public.

The Flight Opportunities for Science Teacher Enrichment (FOSTER) Project allows more than 100 teachers a year to fly on the Kuiper Airborne Observatory. The teachers interact with astronomers and engineers to gain hands-on knowledge of the scientific research process. Here, a teacher tests the spectroscope she constructed in a FOSTER summer workshop. The FOSTER Project is sponsored by the Office of Space Science's Astrophysics Division. (Edna DeVore, SETI Institute, Mountain View, California)

Many excellent collaborative education and public outreach efforts are already under way. Our strategy is to identify, build on, and extend these activities, taking advantage of lessons already learned. Among our guiding principles are coordination with NASA's overall effort to support the national education agenda and goals, compatibility and coordination with national and state efforts toward systematic reform, and support for the establishment of national standards and benchmarks.

Our education and public outreach strategy is centered on actions in six areas:

1. Focus on what educators need

2. Focus on the unique contributions the Space Science Enterprise can make to education and to enhancing scientific and tech nological literacy

3. Forge long-term partnerships with education institutions and professionals

4. Encourage a wide range of educational and public outreach activities

5. Foster full participation of groups currently underrepresented in the space sciences

6. Incorporate the latest communications and information dissemination and display technologies into education and public outreach programs

The Space Science Enterprise will carefully coordinate these activities so that our education programs address the full range of needs of the education community and our outreach programs reach the widest possible audience. We will emphasize infusing education and public outreach into all programs and missions, making education and public outreach a major responsibility for managers and NASA-supported scientists at NASA Headquarters, NASA Centers, universities, and research institutes across the country.

Specifically, the Space Science Enterprise will:

- Continue current support for graduate/post doctoral education and research programs to help create the scientific workforce of the future. We will also expand our support for undergraduate education and training, as well as encourage and support students interested in careers in science teaching.

- Make education and outreach a part of each flight program and research discipline. All major flight projects will have an education and outreach component and a person responsible for education and outreach planning. While every individual investigator will not be required to participate in education and public outreach activities, it is expected that all flight projects and major research discipline areas, taken as a whole, will contribute in a substantive and continuing manner.

- Encourage and promote the involvement of women, underrepresented minorities, individuals with disabilities, minority educators, and minority universities in Space Science activities. We will consult with members, leaders, and representatives of these groups to determine the best ways to achieve this objective. Particular attention will be paid to increasing the contact of women and underrepresented minority students with appropriate professional role models and to the sponsorship of mentorship and internship programs.

- Facilitate scientific involvement in education and public outreach by:
  - Working with the education offices at NASA Headquarters and the Centers to coordinate Space Science-related education and outreach activities both within NASA and with outside organizations and partners
  - Providing incentives such as education and public outreach grants and supplements to NASA-supported space scientists
  - Arranging for the training of scientists in education reform and providing guidance on how to present and develop information and materials in formats that are useful to teachers and effective in the classroom
  - Surveying space scientists for existing education and public outreach activities and updating and distributing the results of these surveys regularly to scientists and the education community
  - Facilitating and encouraging the use of modern communications and information dissemination technologies, including the Internet and World Wide Web home pages, multi-media presentations, and so on
  - Identifying and supporting the development of major education and outreach products, such as curricula, planetarium and museum shows, public exhibits and displays, and so on
  - Facilitating the development of partnerships between the Space Science community and the broad education community, including professional organizations, science museums, planetariums, publishers, the media, and other intermediaries experienced in communicating science results to the public
  - Providing a means of regularly evaluating education and public outreach programs and products both for scientific accuracy and for educational impact and effectiveness

TECHNOLOGY

Identify and Support the Development of Promising New Technologies

New technologies have offered the space science community a clear advantage for enhancing capabilities and enabling new approaches to achieving our goals. With today's technologies, we are achieving orders-of-magnitude greater performance from our scientific instruments using orders-of-magnitude less mass and power. Couple this with the recognized contributions technologies offer toward lowering life-cycle costs, and the recommended course of action becomes obvious. The Space Science Enterprise must maintain a strong advanced technology development program. This, and strong partnerships with the Space Technology Enterprise and the Nation's technology providers, will assure the identification and timely development of the technologies required to achieve the frequent launch of capable, low-cost scientific missions.

Infuse New Technologies into Space Science Programs

The infusion of new technologies into Space Science programs has traditionally been challenging. The reasons are straightforward. Technology infusion requires a substantial upfront investment to support comprehensive testing, risk management, and contingency planning. Typically, flight programs are cost and schedule constrained, and they cannot afford to bear the cost, schedule, and performance risks associated with the aggressive use of new technologies. While each program has tended to infuse new technologies, the rate of infusion has been relatively slow—and directly related to the level of cost and risk acceptable to the individual program.

Given the current and projected fiscal environment, Space Science must take the necessary steps to *aggressively* develop new technologies and infuse them into its programs—and it must do so in a manner that limits the cost and risks to the Enterprise as a whole. The situation is not unique. The Mission to Planet Earth Enterprise faces a similar challenge. As one means of meeting this challenge, NASA has initiated the New Millennium Program. Through New Millennium, NASA will systematically identify, develop, and flight-qualify key technologies that will contribute to lowering life-cycle costs and increasing mission capability and frequency. New Millennium's technology-driven missions will serve as the proving ground for new advances critical to Space Science's future so that, as a whole, the Space Science Enterprise can move boldly into the next century with frequent flights of exciting, low-cost science missions.

Establish Technology Transfer as an Inherent Element of the Space Science Project Life Cycle

The Space Science Enterprise has a responsibility to transfer to the private sector technologies developed in support of its missions. Successful technology transfer requires deliberate, dedicated effort and funding, and it occurs mainly in the context of person-to-person relationships between providers and recipients. Technology is most effectively transferred as it is developed. To this end, the Enterprise has encouraged its community—through its research solicitations and procurement vehicles—to address technology transfer as an integral part of the Space Science project life cycle. To give one recent example of technology transfer, an x-ray sensitive version of Charge Coupled Device detectors developed for the Hubble Space Telescope is being used for digital breast imaging, reducing women's radiation exposure and in many cases replacing expensive and painful surgical biopsies with a more comfortable and less invasive procedure.

Support the Development of Strong and Lasting Partnerships

Productive partnerships among industry, academia, and government provide an environment that facilitates concurrent technology development and transfer. The Space Science

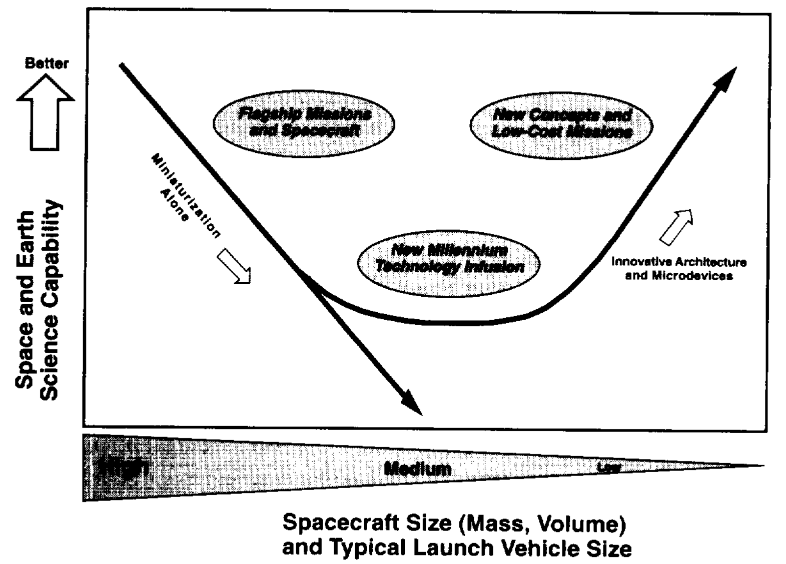
Enterprise will continue to pursue innovative partnering approaches that contribute to achieving technically and scientifically rich missions that provide answers to fundamental scientific questions and contribute to the Nation's global economic competitiveness.

STRATEGIC RELATIONSHIPS

WITH OTHER NASA ENTERPRISES

Relationships with the other Enterprises are essential elements of the Space Science Enterprise strategy. The Space Science Enterprise works with the Human Exploration and Development of Space (HEDS) Enterprise to provide information essential to future human exploration and the development of the solar system. This includes scientific information about likely human destinations, such as the Moon and Mars, surveys and characterizations of space resources, and the evaluation of space radiation hazards. HEDS, in turn, provides the Space Science Enterprise opportunities to accomplish investigations that would otherwise be impractical. For example, Space Science flies payloads on the Space Shuttle, such as telescopes to study the ultraviolet universe, subsatellites to study the solar corona and the origin of the solar wind, and cosmic dust collection experiments. The International Space Station will provide further opportunities for these and other types of investigations. Ultimately, some of the most important and complex science goals, such as answering the question "Did life ever arise on Mars?," will be addressed by human explorers. Indeed, answering questions of this magnitude may well prove to be a significant part of the rationale for human exploration. The synergism between these two Enterprises may thus be profound, and it is certainly essential to the long-range success of both.

Roadmap for Microspacecraft Development



Miniaturizing spacecraft components will reduce spacecraft size. However, low-cost, capable scientific missions of the future will require the infusion of new technologies, such as innovative architectures, increased computational capacity, and microdevices.

Another important relationship is with the Space Technology Enterprise. Space Science Enterprise investment in advanced technology development and infusion is critical to its future success. This effort must include close collaboration between the Space Science Enterprise and its technology providers, particularly the Space Technology Enterprise. In particular, close and successful collaboration will be a critical factor in implementing the New Millennium Program. The Space Science Enterprise, in turn, contributes to the Space Technology Enterprise goal of fostering commercial applications of technology developed for space missions. In addition, Space Science missions provide opportunities to transition technologies between sectors, such as the classified world and the civilian economy.

The Aeronautics Enterprise also makes important contributions to the Space Science Enterprise. For example, Space Science has long taken advantage of Aeronautics expertise at the Ames Research Center to design and build atmospheric entry probes for solar system exploration missions. Ames aeroacoustics and aerodynamics expertise has also been vital in preparing for the SOFIA program. Another example, the Aeronautics Enterprise High Performance Computing and Communications (HPCC) Program, provides the Space Science community access to the most advanced computational technology, which furthers both research and the sharing of results with educators and the public.

The Space Science Enterprise also enriches the Mission to Planet Earth Enterprise through studies of the Sun, the near-Earth space environment, the Earth's middle and upper atmosphere, and other planets. For example, variations in solar radiation and particle emission cause variations in the Earth's atmosphere that are important elements of a full understanding of our terrestrial environment. The study of other planets, particularly Venus and Mars, provide an important context for understanding why the Earth is capable of sustaining life and how some of the processes involved in global change behave in other planetary settings. Ultimately, the better understanding of the Earth's environment sought by the Mission to Planet Earth Enterprise may help us create environments that can sustain humans on other worlds.

With NASA Strategic Functions

The Strategic Functions (Space Communications, Human Resources, and Physical Resources) provide critical enabling capabilities to the Enterprises. The Space Science Enterprise relies on all three Strategic Functions.

The Space Communications Function provides the essential ground-to-space and space-to-ground communications links with operating spacecraft. It also provides ground data processing and distribution services and conducts some mission operations, particularly for Earth-orbiting missions.

At a time of agency downsizing, the effectiveness of both the Human Resources Function and the Physical Resources Function is particularly vital. Like all the Enterprises, Space Science relies on a highly skilled group of scientists, engineers, and support staff to accomplish its missions. The Human Resources Function provides the tools we need to retain and support essential NASA personnel. The Physical Resources Function, in turn, ensures that these personnel have the tools (technical facilities, equipment, office space, information systems, and so on) they need to be effective.

With Other Government Agencies

NASA does not act alone in supporting the pursuit of knowledge about the solar system and the universe. NASA cooperates and coordinates activities with other agencies contributing to this pursuit. Chief among these are the National Science Foundation (NSF), the Department of Energy (DOE), and the Department of Defense (DOD).

NSF has many programs that provide under-pinning for the formulation of NASA Space Science missions. For example, NSF supports ground-based astronomy research that makes vital contributions to the understanding of the universe on which many NASA Space Science missions are based. It also supports programs to study the Sun and its effects on the interplanetary environment that form part of the basis for many NASA studies of the Sun-Earth-heliosphere connection. NSF is also responsible for

U.S. scientific activities in the Antarctic. NASA and NSF have a joint program to use the Antarctic as an analog for the space environment in developing long-range plans for solar system exploration.

DOE similarly has a wide range of programs that support NASA Space Science activities. Most critically, DOE has supplied the radioisotope thermoelectric generators (RTG's) that have enabled a wide range of solar system exploration missions—from Apollo to Viking to the Voyager, Galileo, and Cassini missions to the outer planets. DOE has also contributed greatly to the development of instruments and sensors for NASA Space Science missions, particularly through its Los Alamos and Lawrence-Livermore Laboratories.

NASA-DOD cooperation recently underwent a major development with the flight of the Clementine mission, a joint DOD-NASA mission that surveyed the Moon. Clementine was a program of the former Strategic Defense Initiative Office in the Pentagon. NASA provided science planning support, the mission science team, and support for subsequent data analysis and archiving. Numerous other DOD programs also contribute to the knowledge and technologies required for Space Science missions. Space Science, in turn, contributes to some DOD objectives—for example, through research on the middle/upper atmosphere and the magnetosphere that is important for DOD command, control, and communications sytems.

Other government agencies with which NASA works closely in support of Space Science include the Department of the Interior, particularly its U.S. Geologic Survey and Bureau of Mines, and the Department of Commerce, particularly its National Institute of Standards and Technology.

NASA also cooperates with the Department of Education to realize the Space Science Enterprise goal of inspiring our Nation's youth and improving education in science, mathematics, and engineering.

With International Partners

As discussed above, international cooperation is a fundamental aspect of virtually all Space Science Enterprise programs. The Space Act specifically mandates a leadership role for NASA in promoting international cooperation in space research. In some cases, other agencies and nations contribute to NASA-led missions. In some cases, the leader is a foreign partner.

The quest for knowledge does not recognize national boundaries. Scientific expertise and capabilities are today more than ever distributed among many nations. Common interests and limited resources virtually dictate that nations cooperate in the pursuit of common goals. The Space Science Enterprise regards international cooperation as the accepted norm. We explore the solar system and the universe with our international partners, for the benefit of all.

Recent examples of international collaboration on Space Science Enterprise missions and programs include Galileo, Equator-S, and Roentgen Satellite (ROSAT) with Germany; Hubble Space Telescope, Cassini/Huygens, Ulysses, SOHO, and Cluster with the European Space Agency; Yohkoh and Advanced Satellite for Cosmology and Astrophysics (ASCA) with Japan's Institute of Space and Astronautical Science (ISAS); and Mars exploration and balloon-borne cosmic ray experiments with Russia. Potential future collaborations under discussion with international partners include Astro-E and Astro-F with Japan's ISAS; Rosetta-Champollion with ESA and France; SOFIA with Germany; and Fire (Solar Probe) and Ice (Pluto Express) with Russia.

Conclusion and Summary

Throughout its history, the U.S. Space Science program has been enormously productive. Its accomplishments have rewritten the textbooks. But now, the economic environment has changed dramatically. The Nation's scientific and technological goals are being reexamined and redefined. And the "social contract" between the scientific community and the Federal Government is being rewritten. There is an expectation that the American public should receive more direct benefits from its investment in science and technology.

This Strategic Plan reflects this new paradigm. It presents a carefully selected set of new scientific initiatives that build on past accomplishments to continue NASA's excellence in Space Science. At the same time, it responds to fiscal constraints by defining a new approach to planning, developing, and operating Space Science missions. In particular, investments in new technologies will permit major scientific advances to be made with smaller, more focused, and less costly missions. With the introduction of advanced technologies, smaller does not have to mean less capable. The focus on new technologies also provides an opportunity for the Space Science program to enhance its direct contributions to the country's economic base. At the same time, the program can build on public interest to strengthen its contributions to education and scientific literacy.

With this Plan, we are taking the first steps toward shaping the Space Science program of the 21st century. In doing so, we face major challenges. It will be a very different program than might have been envisioned even a few years ago. But it will be a program that remains at the forefront of science, technology, and education. We intend to continue rewriting the textbooks.

Appendix: Acronyms

ACE	Advanced Composition Explorer
AXAF	Advanced X-ray Astrophysics Facility
ASCA	Advanced Satellite for Cosmology and Astrophysics
CGRO	Compton Gamma Ray Observatory
CNES	French National Space Agency
COBE	Cosmic Background Explorer
DOD	Department of Defense
DOE	Department of Energy
ELV	Expendable launch vehicle
ESA	European Space Agency
EUVE	Extreme Ultraviolet Explorer
FAST	Fast Auroral Snapshot Explorer
FOSTER	Flight Opportunities for Science Teacher Enrichment
FUSE	Far Ultraviolet Spectroscopy Explorer
GP-B	Gravity Probe B
HEDS	Human Exploration and Development of Space (Enterprise)
HESI	High Energy Solar Imager
HPCC	High Performance Computing and Communications
HST	Hubble Space Telescope
IRAS	Infrared Astronomical Satellite
ISAS	Institute of Space and Astronautical Science (Japan)
ISTP	International Solar-Terrestrial Physics
K–13	Kindergarten through introductory college courses
KAO	Kuiper Airborne Observatory
MI	Magnetospheric Imager
NEAR	Near Earth Asteroid Rendezvous
NSF	National Science Foundation
NSWP	National Space Weather Program
OSS	Office of Space Science
ROSAT	Roentgen Satellite
RTG	Radioisotope thermoelectric generator
SAMPEX	Solar, Anomalous, and Magnetospheric Particle Explorer
SIRTF	Space Infrared Telescope Facility
SOFIA	Stratospheric Observatory for Infrared Astronomy
SOHO	Solar and Heliospheric Observatory
SPINS	Special Perspectives Investigation
SWAS	Submillimeter Wave Astronomy Satellite
SXT	Soft X-ray Telescope
TIMED	Thermosphere, Ionosphere, Mesosphere Energetics and Dynamics
TRACE	Transitional Region and Coronal Explorer
XTE	X-ray Timing Explorer

The Space Science Enterprise Strategic Plan is available in electronic form at the following file transfer protocol (ftp) site: ftp.hq.nasa.gov. Log in as anonymous and use your EMAIL ID as the password. Go to the directory "pub/oss/entplan". A "readme" file contains further instructions. The Plan is also available as a World Wide Web document from the Office of Space Science Home Page: HTTP://www.hq.nasa.gov/office/oss.

National Aeronautics and
Space Administration